CHAPTER 3

WATER QUALITY ASSESSMENT

Section I. Designing the Assessment Plan

3-1. Establishing Objectives.

a. General. This chapter provides guidance on setting water quality assessment objectives for programs and/or studies, and on developing designs for reservoir water quality assessment studies. Six typical reservoir study types are considered, and an example of each type is presented for illustration. Before initiating any water quality assessment, the objectives of the program or study need to be specified in a clear and concise manner. This chapter details a process for identifying study objectives and addressing them in a quantitative manner. Once study objectives have been clearly defined, appropriate methods to address them can be selected and a plan of study developed.

b. Interdisciplinary Approach. Assessing reservoir water quality is multifaceted and requires expertise from many disciplines. Since this expertise can rarely be found in any single individual or discipline, an interdisciplinary approach may be required to analyze and address water quality objectives. An interdisciplinary approach implies multiple disciplines (e.g., engineering, physics, chemistry, biology, economics, etc.) cooperating and interacting to address water quality objectives, not simply the assemblage of multiple disciplines working independently on a problem. Corps of Engineers District and Division offices are uniquely suited to using the interdisciplinary approach on water quality issues because the required multidisciplinary expertise exists in many Corps field offices. The three major elements in most field offices--Planning, Engineering, and Construction/Operations--all have responsibility for various aspects of reservoir water quality. Objectives identified and addressed during the initial planning phases can minimize problems during later design phases and, subsequently, during reservoir operation and management.

c. Steps in Establishing Objectives. Establishing the objectives of a water quality program or study is a crucial step in developing a technically sound water quality assessment. Although setting the objectives for a water quality program or study seems to be an obvious step, this process and its documentation are often overlooked. Establishing objectives involves identifying the water quality issues and the potential causes of problems and differentiating the causes from the symptoms. Once the problem or situation has been identified, a written assessment must be completed in order to make the objectives attainable. The objectives should be simple written statements that describe the action to be taken and the measurable key result within a defined time frame and a specified budget.

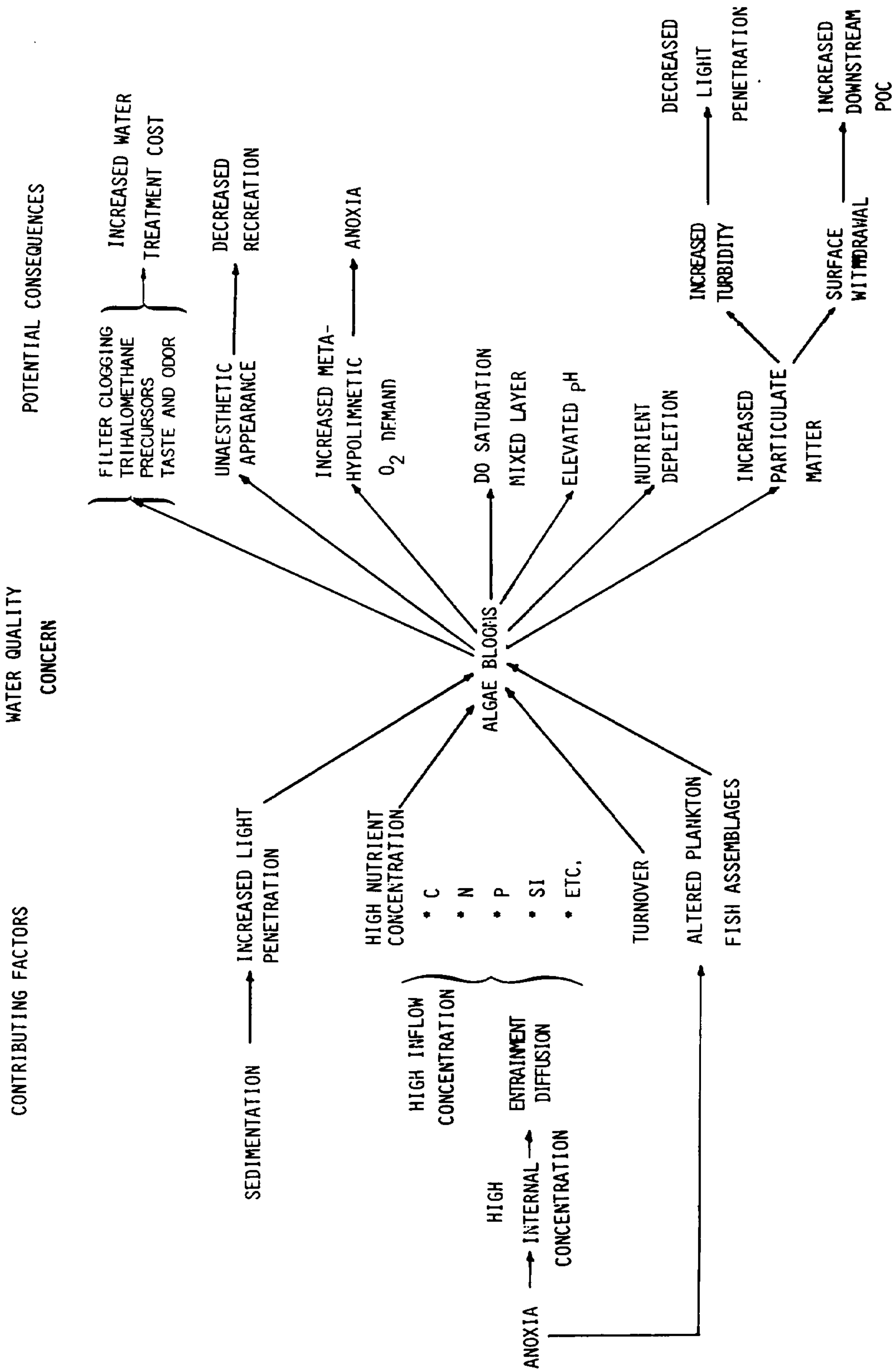

Figure 3-1. Contributing factors and potential consequences of algae blooms

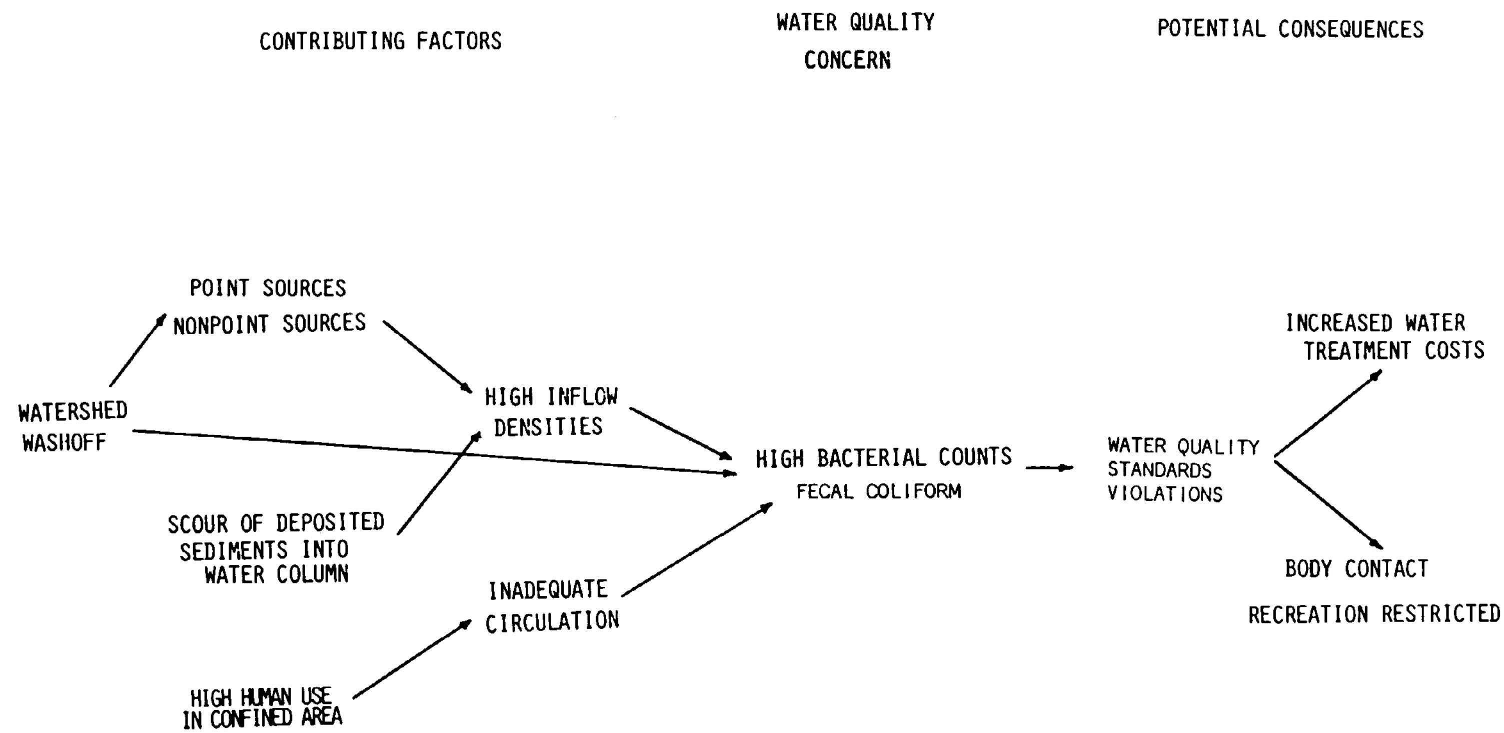

Figure 3-3. Contributing factors and potential consequences of high bacterial counts

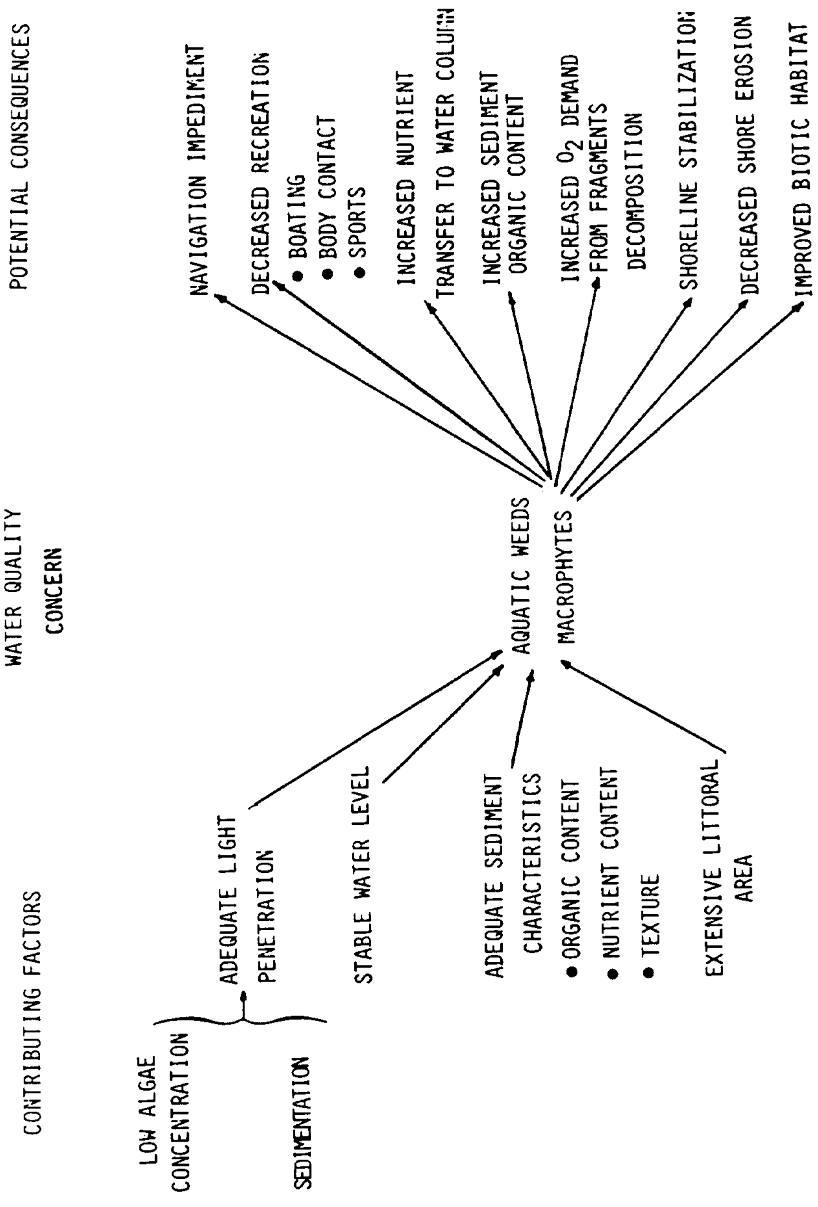

Figure 3-2. Contributing factors and potential consequences of aquatic weed infestations

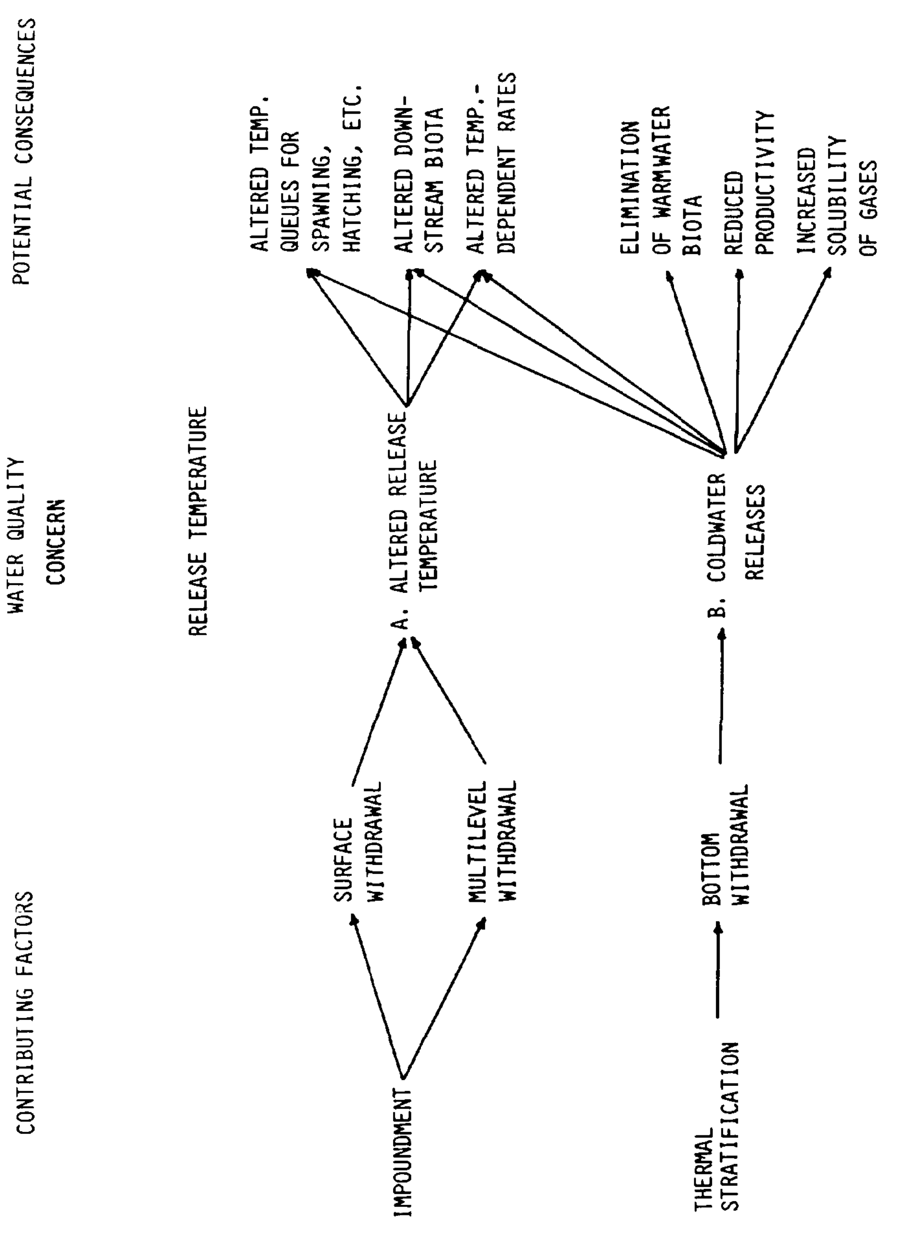

Figure 3-4. Contributing factors and potential consequences of altered release temperatures

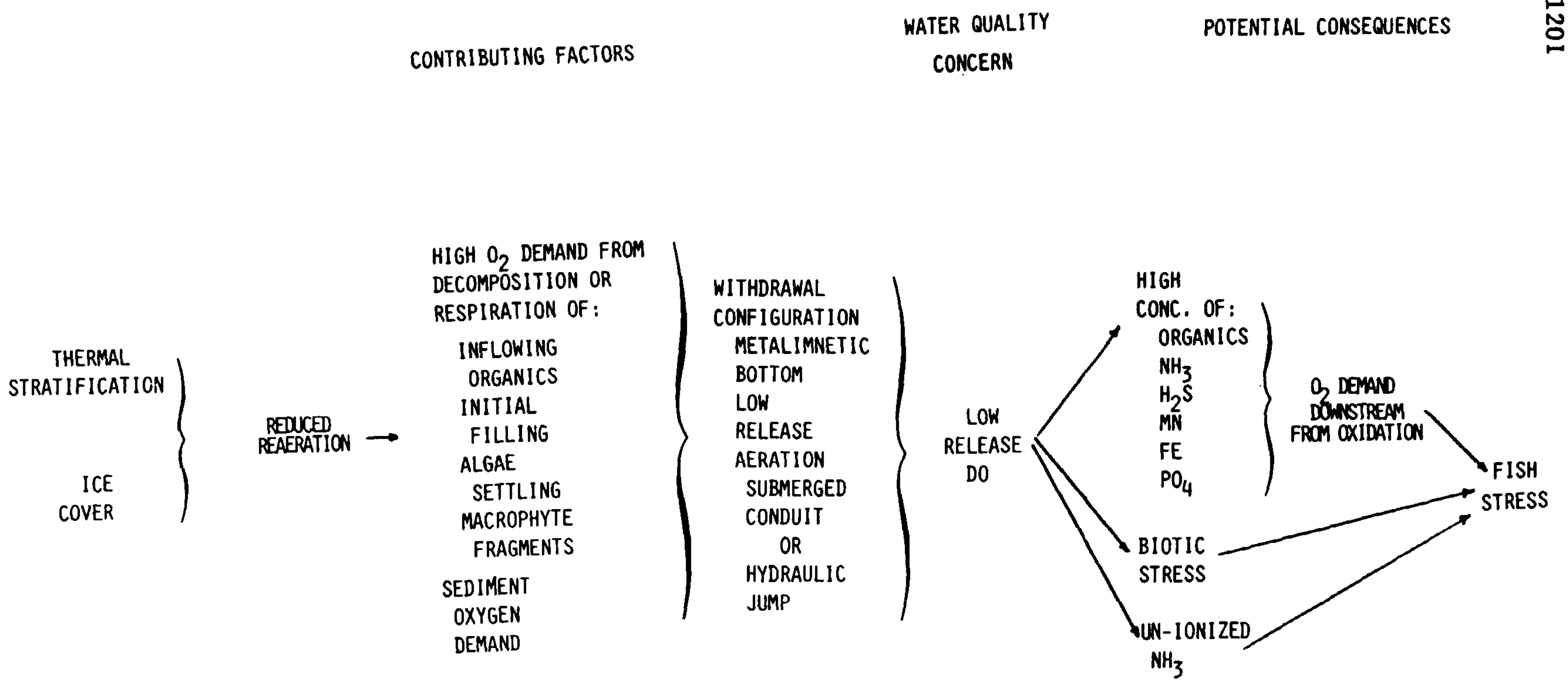

Figure 3-5. Contributing factors and potential consequences of release DO concentrations

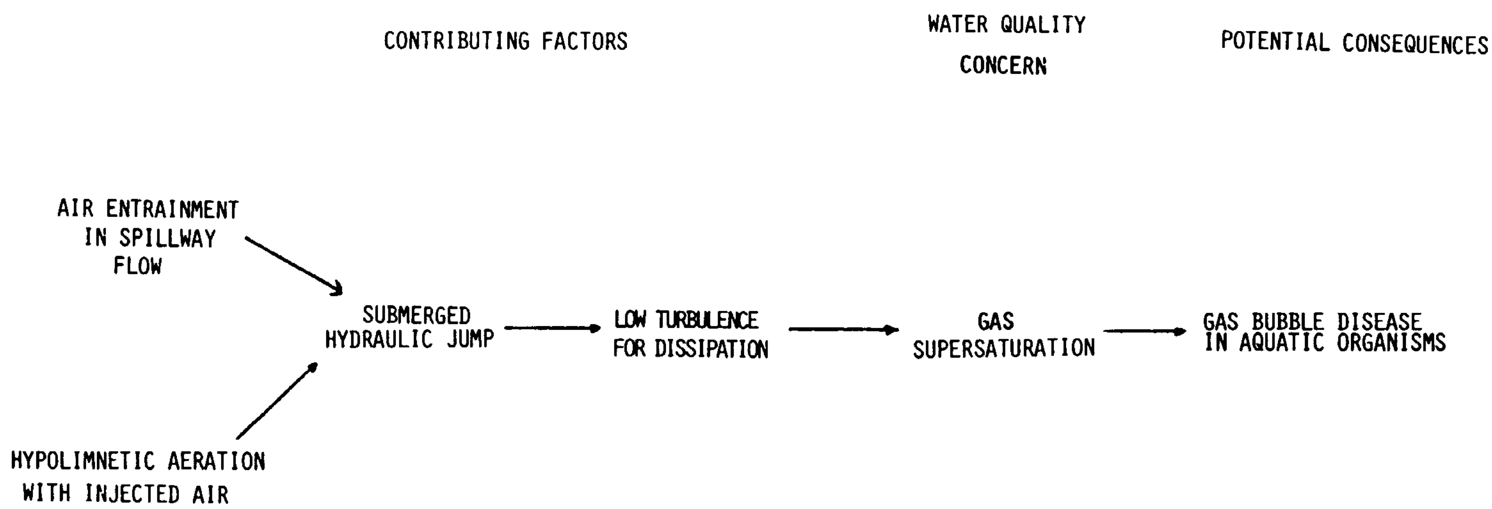

Figure 3-6. Contributing factors and potential consequences of gas supersaturation

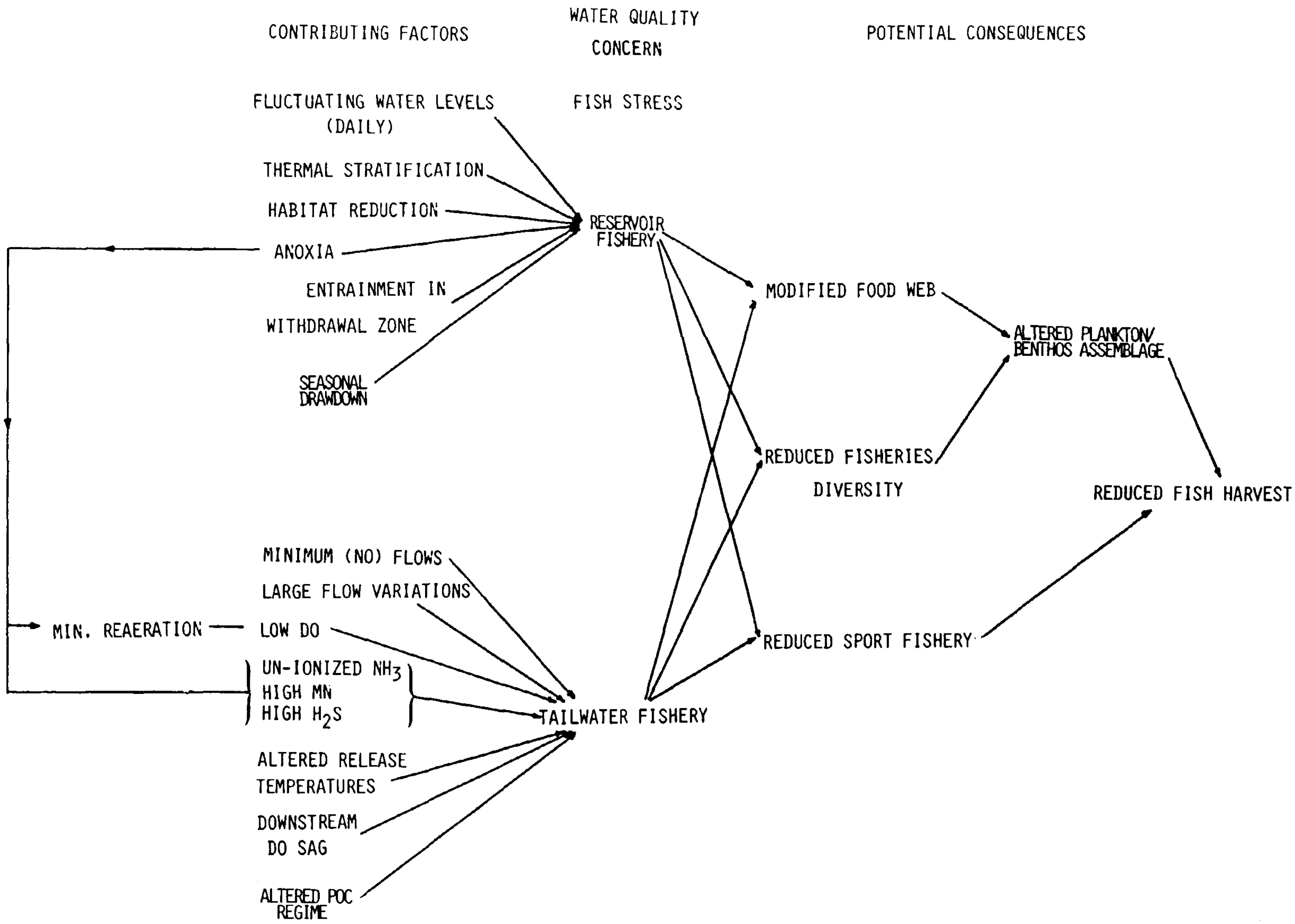

Figure 3-7. Contributing factors and potential consequences of fish stress on both the reservoir and tailwater fishery

TABLE 3-1

Water Quality Concerns and Possible Contributing Factors

POSSIBLE CONTRIBUTING FACTORS \ WATER QUALITY CONCERNS	Large Flow Variations	Scour	Erosion	Mudflats	Cold Release Temp.	Un-natural Release Temp.	Low Release DO	High Release Metals (e.g. Fe, Mn)	High Release NH_3, H_2S	N_2 Supersaturation	High Turbidity	High SS	TDS/Salinity	High Nutrient Conc.	High pH	Low pH	Contaminants	Organics	Taste & Odor	THM Precursors	Algae Blooms	Aquatic Weeds	*E. coli* Bacteria	Fish Stress
Bottom Withdrawal					●		●	●	●								●	●	●	●				●
Plunging Spillway Flow		●								●														●
Hydropower Operation	●	●			●		●	●	●	●							●	●	●	●				●
Fluctuating Water Level			●	●							●	●												●
Stable Water Level																					●	●		
Large Fetch/Waves		●	●								●	●												
Limited Mixing														●							●	●	●	
Extensive Littoral Areas																					●	●		
Watershed Land Use e.g. Agric/Urban							●				●	●	●	●		●	●	●	●	●	●		●	●
High Sediment Inflow							●				●	●		●			●	●				●		●
High Nutrient Inflow							●							●							●			
High TOC Inflow							●										●	●	●	●				
Point Sources											●	●		●	●	●	●	●	●	●	●		●	●
Stratification					●	●	●																	
Ice Cover							●																	
High Evaporation													●	●										
Sed. Oxygen Demand							●																	●
Organic Decomposition							●	●	●					●			●	●	●	●	●			
Anoxia							●	●	●					●			●	●	●	●				●
Reduced Chem. Species								●	●								●	●	●	●				●
Internal Nutrient Load									●					●							●			
High Algal Prod.							●				●				●			●	●	●	●			
High Macrophyte Prod.							●							●	●			●						

(1) Identify water quality concerns. Diagrams similar to Figures 3-1 through 3-7 or a table similar to Table 3-1 are valuable tools in identifying the factors that could potentially contribute to water quality problems. Each discipline and functional group of an interdisciplinary team has a different perspective on water quality concerns, which is important in identifying potential problems.

(2) Identify potential causes. Some water quality concerns occur in nearly all Corps reservoirs and are a result of similar internal processes, external forces, and water control procedures. Seven of these water quality concerns, and their potential causes and consequences, are shown in Figures 3-1 through 3-7. Three of these relate to reservoir water quality; three issues relate to release water quality; and the final concern relates to both the reservoir and tailwater. Similar diagrams can be developed for other specific water quality issues or concerns. Possible causes of other water quality problems are listed in Table 3-1 and may aid in the identification of potential factors affecting reservoir water quality.

(3) Differentiate causes and symptoms. During the identification of potential causes, it is critical that causes be distinguished from symptoms. However, determining the potential causes of a water quality problem can be difficult. Cosmetic, short-lived solutions result from applying management techniques that address water quality symptoms and not causes. Management approaches that address causes typically are more cost effective than approaches that address symptoms. The interdisciplinary group is critical in this phase.

d. Determining Priorities. After needs have been identified and objectives established, a determination must be made as to what work can be done based on the priority of needs and the available resources. When many objectives are involved, management by objective tools, such as decision matrices, is helpful. The developed priorities should be considered tentative and subject to change based on changing needs and resources. Priorities based on program objectives generally differ from those of studies.

(1) Program objectives. Setting priorities for program objectives, such as those that are part of an operational monitoring program, consists of determining those objectives that are basic to the mission of the organization ("must do"), those that are necessary for improving the effectiveness of the organization ("ought to do"), and those that are highly desirable for improving the effectiveness of the organization ("nice to do"). Generally, the "nice to do" objectives are postponed during unanticipated program changes such as budget or personnel reductions. "Ought to do" objectives can be delayed if conditions warrant. Conversely, "nice to do" objectives can be accelerated if personnel or budget conditions improve.

(2) Study objectives. After the water quality concerns have been identified, these should be ordered by dominance, magnitude, controllability, and impact, and a priority should be assigned for formulating management

approaches. For a particular concern, the order of importance and its priority may not be identical. Some issues may be easily addressed with limited funds. These issues may receive a higher priority for initial study than factors requiring longer term planning and coordination with other agencies. A dual priority system may be considered for short-term remedies and long-term solutions.

e. Reevaluation. A reanalysis of water quality concerns and programs may determine that some concerns are more important than originally anticipated. A reevaluation should be conducted, and reassessment of priorities may be required. The evaluation should be an iterative and ongoing process.

f. Modification. Changes in the priority ranking of objectives, or changes in the objectives themselves, should be completed by preparing a revised priority listing of objectives.

3-2. Design Considerations. Once the objectives have been determined, a design or plan of action for achieving those objectives must be prepared. While each design must be tailored to the specific assessment being conducted, the following considerations provide general guidance on the subject.

a. The general characteristics of the assessment should be outlined. Phasing should also be considered, particularly if certain items can only be addressed in sequence or are based on results from another activity. Responsibilities for the various parts must be identified (e.g., is there in-house capability, or will portions or all aspects of the work be contracted?). Level of detail should be described, with scheduling and available resources outlined.

b. It may be helpful to initially evaluate similar studies; many water quality problems or concerns are unique to reservoirs but are common among Federal projects. Discussions with other field operating activities, the Tennessee Valley Authority, or the Bureau of Reclamation can identify ongoing studies, describe consequences or impacts, or warn of pitfalls to avoid.

c. The plan of action will help determine the overall success of the reservoir water quality assessment. It will ensure that the assessment provides conclusions and recommendations that address the specific objectives defined at the beginning, or as redefined during the study. Although this appears obvious, many assessments diverge and subsequently resolve an entirely different set of objectives or problems than originally defined.

d. The design should ensure that the assessment results and conclusions are clearly presented and discussed. In some instances, conclusive results are lost in poor presentation and confusing discussion. As a result, cost-effective, environmentally and technically sound water quality management techniques might not be implemented. The results and conclusions from an assessment need not be voluminous or finely detailed to specifically answer questions, but the information must be clearly understandable.

e. Conclusions and recommendations from all assessments must indicate the reliability of the result and the dependability of the proposed management techniques. These estimates of dependability are essential for rational decision-making in water quality management. A management technique that is 25 percent more expensive but has a 95-percent probability of being effective may be selected over another less expensive technique with only a 50-percent probability of success.

f. Each reservoir project is unique, and the selection and application of appropriate assessment techniques to address issues may require modifications prior to implementation. It should not be assumed that techniques developed for reservoirs in the Northeast are directly applicable to reservoirs in the Southwest and vice versa. Each assessment technique must be carefully evaluated prior to application.

g. A final consideration in designing an effective water quality assessment plan is the importance of project familiarity. Activities such as visiting the project site and working with existing data allow an individual to make common sense or technical judgments pertinent to the quality of the water, problem areas (either existing or developing), and general operating characteristics. This type knowledge cannot be obtained by simply reviewing data. A lack of project familiarity can jeopardize the position of the responsible Corps element should a problem arise.

3-3. Elements of Assessment.

a. Six general categories of reservoir water quality assessment studies are discussed in Section II. A representative example from each category is used to illustrate the general assessment approach. Discussion for each category includes the expected consequences of the proposed actions and a number of program or study definitions.

b. The program or study definitions include known factors, factors to be determined, and assessment techniques, as outlined below.

(1) Known factors. Certain information that is required to address the program or a specific study is readily available before initiating any study. This information includes knowledge of the project purposes; hydrometeorological records; basin and reservoir geometry; water control procedures; and inflow, inlake, or release water quality. This information must be collated for use in subsequent analyses.

(2) Factors to be determined. The unknown factors are dictated by the program or study definition. These are the water quality characteristics that must be determined in order to evaluate whether a reservoir water quality problem may occur and its probable magnitude, duration, and frequency. This must be an iterative process. It is quite possible to address factors that will not contribute to problem solution. This misdirection generally indicates either the problem is not understood or has not been properly defined.

Coordination and discussion of reservoir water quality concerns with the US Environmental Protection Agency (EPA), State and local agencies, or other interested groups can assist in refining study objectives and determining the important factors to evaluate during the study. Most agencies have a greater interest in and are more receptive to study results and conclusions if they were involved in formulating the pertinent study questions and study plan.

(3) Assessment techniques.

(a) There is no single technique or approach for addressing all water quality-related engineering activities or water quality problems. Therefore, the use of only one technique in reservoir water quality studies is not warranted. Each technique has inherent assumptions and limitations that must be considered during technique selection, application, and interpretation of results.

(b) It is important to use the technique that is best for the program or study, not necessarily the technique most familiar to the user. User familiarity is important in technique selection but not to the exclusion of better methods.

(c) Since every reservoir is a unique system, techniques may require modification prior to use. Knowledge of the project characteristics and the assessment technique is crucial for technique modification and accurate analysis. Incorporation of site-specific characteristics in the methodology is generally the best approach for assessing water quality conditions or impacts of engineering design alternatives.

(d) The extent of analysis and the required detail are determined by the program or study scope, available information, required resolution, and engineering and scientific judgment. Some water quality concerns can be resolved in a day using order of magnitude estimates, while other water quality concerns may require field and laboratory investigations and mathematical and physical model applications that extend for a year or more to develop satisfactory management alternatives.

(e) One generalization is valid over the broad range of analytical techniques. That is, an integrated approach, using multiple techniques, results in a more reliable, cost-effective, and sound engineering analysis of potential water quality problems and the alternative management approaches.

Section II. Water Quality Assessment Program/Study Categories

3-4. Preimpoundment Assessment. A preimpoundment assessment predicts the reservoir water quality conditions that are likely to occur in and below a project if it were constructed and operated under a specific engineering design and water control plan. In general, a preimpoundment assessment evaluates several alternative engineering designs and alternative water control plans.

a. Expected Consequences. The obvious consequence of a proposed reservoir is that a free-flowing stream or river will be impounded. General reservoir water quality characteristics and water quality patterns that can be expected are discussed in Chapter 2. Study of the reservoir water quality at surrounding reservoirs with similar structural designs and water control plans provides valuable insight into the water quality patterns and problems to be encountered at the proposed study site. For most reservoirs, dynamic water quality changes can be expected for the first 6 to 10 years following impoundment, during the transition period.

b. Program/Study Definition. Two related concerns associated with any preimpoundment assessment, regardless of project type, are whether postimpoundment water quality will satisfy: (1) both inlake and release water quality objectives and (2) project purposes. Water quality conditions in similar reservoirs in the project area should be examined along with any design or operational modifications made or proposed to improve water quality conditions in these surrounding projects; this information should be included in the problem definition.

(1) Known factors. Factors that should be known at the beginning of the analysis, regardless of the engineering activity, are summarized in Figure 3-8. Reservoir and release water quality data will not be available for preimpoundment studies, but the remainder of the information can be compiled. Sources of information that should be consulted are indicated in Chapter 4.

(2) Factors to be determined. A number of unknown factors must be addressed during the water quality assessment to determine if reservoir water quality objectives can be attained. Typical unknown factors are summarized in Figure 3-9 and include:

(a) Inflow water quality conditions. Existing stream water quality conditions must be compared with applicable State and EPA criteria and standards during the preimpoundment assessment. If the existing stream water quality does not meet water quality criteria or standards, alternative designs or water control plans should be evaluated to minimize the impact of these violations on reservoir water quality.

(b) Stratification. The onset, duration, strength, and overturn of stratification dictate water quality conditions that may occur following impoundment. These conditions range from downstream temperatures that are

- Basin and reservoir geometry including elevation-area-capacity relationships for the reservoir.
- Hydraulic outlet design and geometry.
- Reservoir routings and operations data for the period of record under alternative water control plans.
- Existing stream water quality.
- Meteorological conditions within the basin from National Weather Service stations located as near the proposed site as possible.
- The locations and water quality characteristics of surrounding water bodies.
- Land use within the watershed.
- Existing reservoir water quality conditions.
- Existing reservoir release water quality conditions.

Figure 3-8. Project characteristics known prior to beginning a water quality study

- Inflow quality and inflow placement in the reservoir
- Inlake water quality conditions with emphasis on:

    Temperature regime

    DO regime

    Algae concentrations and succession patterns

    Withdrawal zone

- Release water quality conditions with emphasis on:

    Temperature

    DO

    Metal concentrations (Fe, Mn)

    Organics

    NH_3 and H_2S

Figure 3-9. Typical water quality factors to be assessed in reservoir water quality studies incompatible with the water use objective to high iron concentrations in reservoir releases from an anoxic hypolimnion. Accurate stratification predictions are required to assess potential water quality concerns and develop appropriate management approaches.

(c) Dissolved oxygen regime. Determination of the hypolimnetic oxygen demand and depletion rates in conjunction with the strength and duration of stratification can indicate the potential for and duration of anoxic conditions. This may impact both inlake and reservoir release water quality.

(d) Inflow and withdrawal zones. Seasonal changes in the thickness and location of the inflow zone may influence the availability of inflowing nutrients to phytoplankton in the euphotic zone, contribute organic matter to the metalimnion or hypolimnion that may deplete DO in these two areas during microbial decomposition, or provide sufficient energy to create additional mixing and entrainment between the epilimnion and metalimnion or the metalimnion and hypolimnion. The thickness and location of the withdrawal zone may withdraw cold water; withdraw anoxic water; blend warmer, oxygenated water with hypolimnetic water; or entrain water from these stratification zones, which will influence release water quality. The inflow placement and withdrawal zones should be determined for an annual cycle.

(e) Productivity. Phytoplankton species assemblages, successional patterns, biomass, and chlorophyll concentrations must be estimated. This information may indicate potential problems for project purposes such as water supply (trihalomethane precursors, taste and odor, filter clogging), recreation (nuisance algal blooms, surface films), and fish and wildlife enhancement or mitigation. Primary productivity, as previously mentioned, may also influence secondary and tertiary (fish) productivity.

(f) Release quality. Release water quality should be determined and compared with downstream water quality objectives. Reduced constituents released from an anoxic hypolimnion can markedly influence downstream objectives. Oxidation of manganese (II), iron (II), and hydrogen sulfide; nitrification; and organic matter decomposition may exert an oxygen demand downstream in addition to violating stream water quality criteria and standards.

(g) Criteria and standards. Project purposes such as water supply, irrigation, recreation, and fish and wildlife conservation may be impacted if water quality criteria and standards are not satisfied. Both inlake and reservoir release water quality should be compared with applicable criteria and standards.

c. Assessment Techniques.

(1) The selection of appropriate techniques to assess the water quality of a proposed reservoir depends on the stage in project design, problem definition, and required resolution. All of the assessment techniques, with the obvious exception of field studies (since no reservoir exists), are

appropriate and have been used in preimpoundment water quality studies. Review of available information and similar studies on other projects, simple calculations, and analyses of existing water quality data should be conducted at all phases of project planning and design. The study objectives should determine the level of detail and accuracy required and used in the study.

(2) During the preliminary phase of project design, order of magnitude estimates may be sufficient to screen alternatives. If water quality data on the river and surrounding water bodies are not available, field studies should be designed and implemented to collect data on representative systems. As greater problem resolution is required, more detailed information, such as nutrient loading models, and statistical techniques, such as regression analyses or time series analyses, may be appropriate to provide mean annual estimates or seasonal estimates of representative water quality constituents.

(3) Advanced design considerations warrant the use of mathematical models for water quality prediction and the selection of final design and operation criteria to achieve water quality objectives. In addition, physical model studies may be required to define withdrawal zones, and laboratory studies may be required to determine chemical and biological process rates. These techniques have been used in combination to provide an integrated assessment of expected reservoir water quality in various preimpoundment studies.

3-5. Postimpoundment Assessment.

a. General.

(1) A postimpoundment assessment measures the reservoir water quality conditions that have occurred following construction. During the early postimpoundment period, the water quality characteristics are unstable; this period has been termed the trophic upsurge period. The duration and intensity of the trophic upsurge period vary among reservoirs due to factors such as geographic location (latitude), site preparation, and filling schedule.

(2) Reservoirs in the northern latitudes tend to have shorter trophic upsurge periods than reservoirs in southern latitudes.

(3) Site preparation can range from timber removal, through secondary vegetation removal and debris removal, to topsoil removal. Also, partial clearing between specific elevations and retention of timber in selected locations are sometimes part of site preparation. Additional site preparation often involves construction of drainage ditches to ensure that all marginal pools, sloughs, and depressions fluctuate freely with the main reservoir. All these activities must be included in the postimpoundment evaluation.

(4) In general, a postimpoundment assessment evaluates the physicochemical and biological changes during the trophic upsurge period using those specific diagnostic techniques identified in the preimpoundment assessment. It can serve as a basis for evaluating the adequacy and quality of the predictive

techniques used during the preimpoundment investigations. The postimpoundment assessment is important for guiding water control management during the transition phase following impoundment.

b. Expected Consequences. The expected consequences of a new reservoir include changes in water quality, which may deteriorate existing conditions (as discussed in Chapter 2), as well as changes in the aquatic biota of the original riverine system. Preimpoundment predictions and water quality conditions of surrounding reservoirs with similar structural designs and water control plans can provide comparative guidance as to when the trophic upsurge period is over.

c. Program Study Definition. The two major concerns associated with postimpoundment conditions involve whether: (1) the transitional reservoir water quality following impoundment is satisfying inlake and release predictions and objectives and project purposes, and (2) post-transitional water quality will meet project purposes. Any design or operational modifications made or proposed to improve the temporary water quality conditions in the reservoir should be reviewed and incorporated in the program or study definitions.

(1) Known factors. The known factors at the beginning of the program or study are the same as those identified for preimpoundment assessments. Knowledge of existing water quality and release water quality includes inflow quality and placement in the reservoir, inlake water quality conditions (water temperature regime, DO regime, algal concentration and succession patterns, and withdrawal zone), and release water quality conditions (water temperature; DO; metals (Fe and Mn) concentrations; and organics, NH_3 and H_2S). (See the discussion on preimpoundment assessment (para 3-4) for a further description.) The water quality of both inlake and reservoir releases should be compared to applicable criteria and standards.

(2) Factors to be determined. The postimpoundment water quality conditions must be compared with applicable State and EPA criteria. The unknown factors that must be addressed during the postimpoundment period to determine if reservoir water quality objectives can be attained are discussed briefly below.

(a) Inflow water quality. Alternative water control plans should be considered when the existing inflow stream water quality does not meet state or Federal water quality criteria.

(b) Stratification. The establishment, duration, and strength of stratification and occurrence of overturn will play a major role in the other physicochemical and biological conditions that may occur following impoundment. The initial filling rate criterion and the hydrologic condition will determine if a reservoir is partially or completely filled in one storage season. The amount of water stored during the first filling season, and the length of ti- necessary before reaching full-pool conditions, will play a dominant rolthe water temperature stratification characteristics during the trophic upsurge period.

(c) Dissolved oxygen regime. The hypolimnetic oxygen consumption rate of a new reservoir will be determined by such factors as the size of the hypolimnion, water retention time, the amount of biodegradable organic material available, and the water temperature. In new reservoirs that have large hypolimnia, are cleared of organics, have moderate to long retention times (30 to over 365 days), and have hypolimnion water temperatures between 4° and 8° C, the hypolimnetic oxygen consumption rates tend to be linear. New reservoirs that have small hypolimnia, are cleared of organics, have long or short retention times, and have hypolimnion water temperatures above 8° C can exhibit hypolimnetic oxygen consumption rates that have polynomial decay characteristics. New reservoirs also can exhibit oxygen depletion higher in the water column, usually in the metalimnion region, due to microbial decomposition. This occurrence is often most apparent in the lacustrine zone near the dam.

(d) Inflow and withdrawal zone. Changes in the thickness and location of the inflow zone can change several factors important to water quality considerations. Energy that creates additional mixing and entrainment, nutrient availability to the euphotic zone, and organic contribution to the metalimnion and hypolimnion can become important unknown factors for postimpoundment programs or studies. The thickness and location of the withdrawal zone also can change several factors important to water quality. Release water quality is affected by the withdrawal of cold water, anoxic water, or blended water. The characteristics of the inflow placement and the withdrawal zones, therefore, are important factors to be determined at new reservoirs.

(e) Productivity. Phytoplankton species, patterns, biomass, and chlorophyll concentrations should be determined at new reservoirs. Potential problems that could affect project purposes such as water supply, recreation, and fish and wildlife should be identified. Phytoplankton present at a new reservoir can be different from those present in a mature impoundment.

(f) Release quality. The quality of the water being released from a reservoir should be determined and compared with downstream water quality objectives, State standards, and/or Federal criteria. Constituents such as manganese, iron, hydrogen sulfide, and ammonia released from an anoxic hypolimnion can markedly influence downstream objectives.

d. Assessment Techniques. Selection of appropriate analytical techniques to evaluate reservoir water quality conditions are usually determined before postimpoundment fieldwork is initiated. There will be heavy reliance on field observation and data collection as the diagnostic technique in this phase. Data evaluation techniques used in the preimpoundment studies are usually appropriate. However, during some phase of the postimpoundment program or study, it may be necessary to introduce new analytical techniques that would indicate unanticipated water quality developments. Simple calculations and analyses of existing data should be conducted at all phases of the postimpoundment program or study. Regression analyses or time series analyses may be appropriate to provide seasonal or annual estimates of the important water quality constituents.

3-6. Operational Monitoring. Operational monitoring is implemented to establish baseline water quality conditions and changes, identify water quality problems, provide guidance to water control elements for effective water quality control, and provide a database for coordination with other agencies. In general, operational monitoring is long term and should cover the life of the project. Assessment occurs with each set of data collected to evaluate short- and long-term trends and/or changes.

a. Expected Consequences. The consequences of operating a reservoir range from meeting all water quality objectives to not meeting any objectives. If the water quality assessment indicates no problems, then no action is required. If a water quality problem is encountered or predicted, a remedial or corrective course of action may be recommended and may include a change in water control facilities and/or the water control plan. Data collected under these programs are used in a variety of applications and serve as a valuable database for other types of studies (e.g., recreation planning, drought contingency, change in project purpose).

b. Problem/Study Definition. The major question associated with operational monitoring regards the effectiveness of the project in meeting water quality objectives. If a project is not attaining water quality goals, operational monitoring should reveal the first evidence of a problem. The monitoring program should be broad enough in scope to identify potential problems in any major area (trophic status, contaminants, recreation, etc.) and yet remain cost effective. Once a problem has been identified, other types of studies should be initiated to define alternatives.

(1) Known factors. Known factors about the reservoir should include morphologic type (dendritic, prismatic, etc.) and features, hydrologic record, and operational plans and constraints. Knowledge of the watershed characteristics and activities should provide a general indication of inflow water quality. Once a project has become operational and water quality monitoring begins, a database will be available for comparative analyses.

(2) Factors to be determined. The unknown factors involved in an operational monitoring program are numerous but may be classified as either definable or undefinable. Definable factors are those water quality characteristics which through the monitoring program may be identified and, if necessary, modified. Undefinable factors are those that may impact the water quality but only the symptom or effect is observed. For example, a fish kill may result from oxygen depletion or viral infection. If immediate sampling is not conducted, there may be no measurements to indicate the cause of the fish kill.

c. Assessment Techniques. The method of analysis depends on the type of reservoir, operational scheme, anticipated water quality problems, and water quality objectives. The monitoring will usually involve field studies and may include other types of studies. Data collected should be examined for deviations from Federal or State criteria and in regard to eutrophication aspects as well as recreation interests. Data interpretation should be made in relation to project objectives and reported in accordance with ER 1130-2-334 (see Chapter 4). Alternatives identified as a result of operational monitoring must be reported to the appropriate responsible element.

3-7. Modification of Operations. A typical nonstructural modification may be an operational change. Operational modifications generally involve changing the reservoir water control plan or guide curve. This modification may be proposed because of in-reservoir uses, reduced volume of the reservoir caused by sedimentation, or downstream water uses. Prior to modifying a guide curve, however, potential impacts on reservoir water quality should be assessed.

a. Expected Consequences. The expected consequences of the proposed modification are related to the change in pool elevation, surface area, and reservoir volume. A small increase in pool elevation may have minimal impact on reservoir water quality since the shallow water column over the newly inundated areas will probably not become anoxic. Large pool elevation changes, however, can significantly modify the depth, surface area, volume, and residence time of the reservoir and, as a result, may have a significant impact on reservoir water quality. As a result of these changes, the epilimnetic and hypolimnetic volumes may increase during periods of stratification. The location of the thermocline may rise in elevation but remain about the same distance below the water surface as in the existing reservoir. Reservoir water quality may be degraded during the first 6 to 10 years following an increase in storage (transition period) due to the inundation of terrestrial vegetation and organic soil. Substantial water quality changes may occur if the hypolimnetic DO is depleted due to this change. The length of the anoxic period influences the magnitude and types of water quality changes that occur. Some natural hypolimnetic aeration may occur when oxygenated interflows or underflows enter the hypolimnion, but the oxygen carried in these flows is generally insufficient to satisfy the hypolimnetic oxygen demand if the reservoir residence time is relatively long.

b. Program/Study Definition. The initial program or study is to determine the potential for water quality changes as a function of operational modifications. Small pool elevation changes or minimal phase changes in the rule curve may have no significant impact on reservoir or release water quality. However, large pool elevation changes may result in extensive mudflat formation, inundation of terrestrial areas, and altered reservoir and release water quality. If large pool elevation changes occur, water quality problems may be similar to those encountered in proposed impoundment studies since terrestrial areas could be inundated. Changing release depth, however, may result in water quality problems similar to those encountered with structural modifications. A review of other District projects with a similar operation may produce better problem definition and resolution.

(1) Known factors. Factors for which information should be available at the beginning of the analysis are listed in Figure 3-8.

(2) Factors to be determined. The unknown factors related to operational modifications are indicated in Figure 3-9 and are similar to those discussed for structural modifications.

c. Assessment Techniques. Information on similar operational modifications and observed water quality conditions should be reviewed and simple calculations performed to determine changes in residence times, stratification potential, shoreline development ratios, and other similar factors. Nutrient loading models may indicate increased or decreased inlake nutrient concentrations, hypolimnetic oxygen demand, chlorophyll concentrations, transparency estimates, and trophic state classification provided the change in storage is significant. Mathematical models provide an effective means of evaluating a number of operational alternatives. Physical and mathematical models can provide information on changes in reservoir hydrodynamics under several hydrologic and regulation regimes. Laboratory and modeling studies can be used to indicate potential anaerobic problems that may occur with an increase in storage and inundation of a terrestrial area.

3-8. Modification of Water Control Structures. Typical structural modifications include the addition of a submerged weir or selective withdrawal capabilities to improve inlake and/or downstream water quality.

a. Expected Consequences. The expected consequences are a function of the purposes for modifying the structure. Addition of selective withdrawal to a structure with bottom sluice gates to meet a natural downstream temperature objective may result in: stronger stratification profiles throughout the pool, a longer stratification period, colder hypolimnetic temperatures, longer hypolimnetic residence times, greater potential for an anoxic hypolimnion, increased surface discharge, cooler surface temperatures in the spring and early summer, a possible shift in phytoplankton succession with the altered thermal regime, and potential shock loading on the downstream system if the bottom sluice gates must be used to pass stormflows. Addition of a submerged weir to a bottom sluice gate structure may result in: greater surface discharge; a shallow, cooler epilimnion and a larger, colder hypolimnion; an anoxic hypolimnion; shift in phytoplankton succession; low DO throughout the pool at overturn; and a longer stratification period. Similar modifications made in other projects should provide insight into the expected consequences in the prototype.

b. Program/Study Definition. The primary problem is to determine if the structural modifications can satisfy downstream water quality objectives and maintain or enhance reservoir water quality. One hydraulic outlet design may improve reservoir water quality while an alternative design may improve release water quality. Structural modifications should be selected to minimize the impact on reservoir project purposes but to attain inlake and downstream objectives. Operational considerations must be included as part of the design criteria. A major problem with many selective withdrawal structures is that the inlet portals are not designed to pass large flows and the bottom floodgates must therefore be used to pass storm events. This change in withdrawal depth may result in shock loading of cold water, which is potentially low in DO and high in nutrients and other constituents, to the downstream system.

(1) Known factors. Factors that should be known at the beginning of the assessment are listed in Figure 3-8. An additional factor that should be known is any operational problems associated with structures similar to the proposed hydraulic design.

(2) Factors to be determined. Several unknown factors that need to be assessed to evaluate the effectiveness and impact of the structural modification are summarized in Figure 3-9 and include:

(a) Criteria and standards. The sources or causes of violations in water quality criteria and standards must be identified and used to evaluate the effectiveness of the proposed structural modification in improving the water quality conditions. Some hydraulic outlet designs may be more effective in minimizing certain conditions than other designs.

(b) Stratification. Since the general intent of many structural modifications is to meet a downstream temperature objective, it is important the thermal regime in the pool be accurately predicted.

(c) Inflow and withdrawal zones. An altered thermal regime can influence or alter the inflow and withdrawal zones. Inflow placement and withdrawal zones are directly influenced by the density distribution within the pool. Accurate predictions of withdrawal zones are required to determine if a downstream temperature objective can be met.

(d) DO regime. Stronger stratification may diminish reaeration across the metalimnetic interface and result in an anoxic hypolimnion. Stronger stratification may also result in oxygenated stream inflows proceeding as interflows, further reducing hypolimnetic oxygen supplies. Development of an anoxic hypolimnion may result in entraining and/or discharging higher concentrations of phosphorus, ammonia, manganese (II), iron (II), and hydrogen sulfide in the reservoir releases. The impact of the structural modification on the DO regime in the pool and the potential for anoxic conditions may alter proposed hydraulic designs and operational plans.

(e) Productivity. Biological and chemical reaction rates are temperature dependent, so an altered thermal regime may result in changes in the phytoplankton community and higher trophic levels. Increased nutrient concentrations associated with an anoxic hypolimnion may be entrained in the mixed layer and promote increased productivity. Additional surface discharge may result in higher mixed-layer nutrient concentrations and also stimulate additional productivity. Changing the temperature and depth of the mixed layer may alter the successional pattern of the phytoplankton community, reducing or intensifying problem algae such as blue-green bacteria.

(f) Release quality. Structural modifications are generally used to meet a downstream release target for flow, temperature, DO, or other objectives. The predicted release quality, therefore, must be compared with the downstream objective. For a constituent such as DO, it is also important to consider the impact farther downstream. While the releases may be saturated with DO from reaeration in the conduit, chemical and biological oxygen demands associated with various release constituents may create an oxygen deficit and sag farther downstream. Oxidation of hydrogen sulfide, iron (II), and manganese (II); nitrification; and organic decomposition of release constituents, particularly from an anoxic hypolimnion, should be considered and routed downstream to assess their impact on the downstream aquatic community.

c. Assessment Techniques. Information on the impact of similar hydraulic designs and operation plans on reservoir water quality should be compiled and simple calculations performed. Since the structural modification primarily influences the zone of withdrawal and not the flow rates, nutrient loading models may not be as appropriate as other techniques since the surface area, volume, total nutrient loading, hydraulic loading, and residence time are not changed by modifying the zone of withdrawal. Determination of the design of the selective withdrawal structural and the resulting reservoir and release water quality should include a reservoir water quality model. Selection of a specific model should consider other reservoirs in the system, the interaction of the reservoirs, the need for stream simulations, and the degree of detail required in the water quality simulations. Physical models may help describe changes in withdrawal zones resulting from the structural modification. Laboratory studies may be required to modify model reaction rates for changes in nutrient and anaerobic processes.

3-9. Specific Water Quality Problems. Any number of examples could be discussed. The example used in this discussion is a bridge construction project causing a local constriction in a reservoir.

a. Expected Consequences. Two major consequences can be expected to occur as a function of the constriction: acceleration of flow through the localized area and a backwater effect upstream of the constriction. The basic hydraulic relationship, $Q = AV$, indicates that a reduction in cross-sectional area A must be compensated by an increase in velocity V in order to continue to pass a given flow Q. A localized constriction reduces the cross-sectional area so the velocity at a constant flow rate increases in the constriction. This localized velocity increase may disrupt stratification and produce a well-mixed zone in this area. The localized constriction may also create a backwater effect upstream, resulting in increased sedimentation of both inorganic and organic suspended solids. Depending on the stratification pattern and hypolimnetic volume, this increased organic deposition may result in sufficient oxygen demand to promote anoxic conditions. Increased sedimentation can result in loss of storage volume in this upstream area.

b. Problem Definition. The location of the bridge site is important if upstream water quality conditions are to be maintained. Location of a constriction near the headwater may result in extensive mudflat formation upstream from the bridge. This area can be highly visible to bridge traffic. Sampling stations need to provide information that is representative of the general water conditions in the pool and near the proposed bridge site. Location of these sampling sites at points where bridges cross a reservoir, while convenient, may not represent water quality within the pool and may result in erroneous conclusions concerning existing reservoir water quality conditions.

(1) Known factors. Information available at the initiation of the impact assessment should include (Figure 3-8):

(a) Reservoir geometry including shoreline configuration and cross-sectional areas.

(b) Sedimentation survey results including areas of erosion and deposition, relative sedimentation rates, and specific transect geometry.

(c) General circulation patterns, residence times, flow regime, sediment loads, trap efficiency, outflow sediment concentrations, and operation records.

(d) Existing water quality prior to modification, including stratification profiles, thermal regime, and nutrient and organic loading and retention.

(e) Release water quality and downstream objectives.

(2) Factors to be determined. There are several unknown factors that must be addressed to assess the impact of the proposed modification (Figure 3-9). These factors include:

(a) Backwater effects. The backwater effects of the construction need to be assessed to determine the extent of the upstream effects and potential areas of impact.

(b) Sedimentation. Previous sediment loads and sedimentation records need to be used to predict the sedimentation regime following reservoir constriction. This should include both inorganic and organic suspended solids.

(c) Stratification. The upstream and downstream stratification patterns should be estimated following constriction.

(d) DO regime. Increased organic sedimentation upstream of the constriction may produce additional oxygen demand due to increased microbial decomposition of this organic matter. Stratification may result in the development of an anoxic hypolimnion and the resolubilization and release of nutrients and metals into the overlying water column.

(e) Nutrient regime. Increased sedimentation and decomposition of particulate organic matter may increase nutrients upstream of the constriction.

(f) Productivity. Increased nutrient concentrations may promote and stimulate phytoplankton production, resulting in nuisance algal blooms.

(g) Lower reservoir. The influence on reservoir water quality downstream of the constriction also needs to be assessed. Water quality conditions may significantly improve downstream with the removal of inflowing sediments, nutrients, and organic matter. Increased light penetration downstream, however, may also enhance phytoplankton productivity and create other conditions such as taste and odor, surface films, and unaesthetic conditions.

(h) Release quality. The location of the constriction may improve release water quality if the majority of the particulates are removed prior to discharge downstream. A location near the outlet tower, however, may minimize control over release quality and result in diminished release water quality.

c. Assessment Techniques. Existing information on the effects of flow constrictions can be found in most hydraulic engineering texts (e.g., Ref. 74). Existing water quality data collected from areas where localized mixing may occur should be reviewed carefully to avoid erroneous conclusions. Remote sensing has been used to analyze surface turbidity plumes and can provide qualitative evidence of local acceleration and sedimentation in other similar projects. Physical and two-dimensional numerical models can indicate changes in flow, backwater effects, and circulation patterns due to constriction and may indicate the potential for destratification if a stratified two-layer system is used. Mathematical sediment transport and water quality models can be used to predict sedimentation rates and patterns, hypolimnetic oxygen depletion rates, nutrient cycling, and productivity upstream and downstream from the constriction, including release water quality.